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Weiler. and Kane.

Voltage Regulation Of Gasoline-Electric Units.

VOLTAGE REGULATION

OF

GASOLINE-ELECTRIC UNITS

BY

EDWARD GROVER WEILER

AND

ROBERT CLAIR KANE

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1916

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UNIVERSITY OF ILLINOIS

May 31, 1916.

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Edward Grover Weiler and Robert Clair Kane

ENTITLED Voltage Regulation of Gasoline Electric Units

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

J. W. Fisk
Instructor in Charge

APPROVED: Ellery B. Paine

HEAD OF DEPARTMENT OF Electrical Engineering

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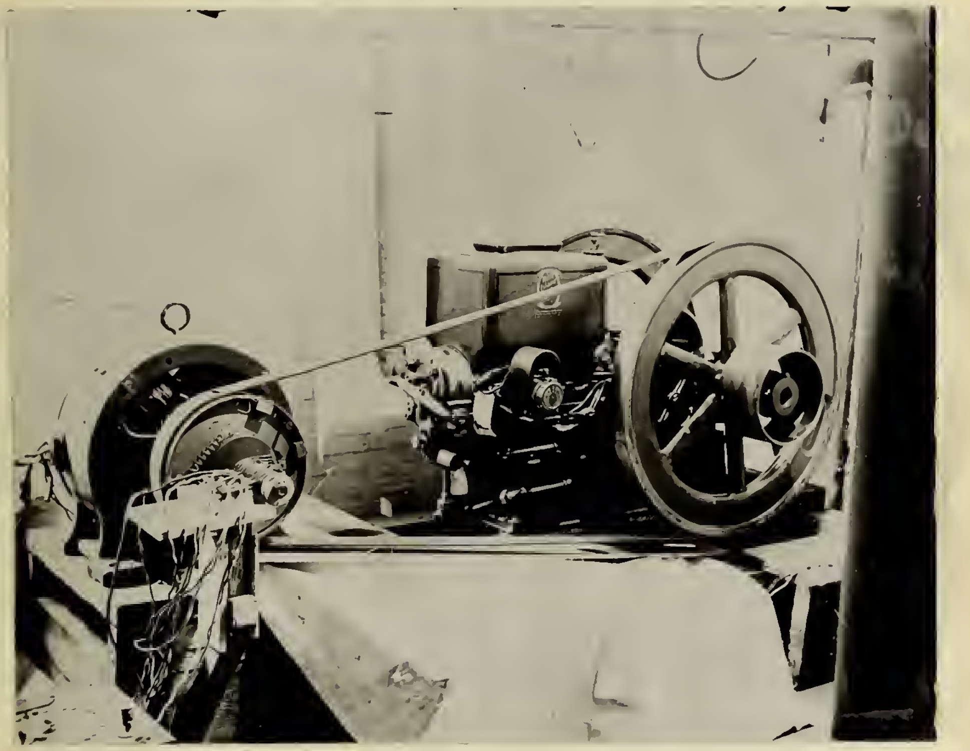

Fig. 1.

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VOLTAGE REGULATION OF GASOLINE ELECTRIC UNITS.

I

INTRODUCTION

OBJECT:

The object of this investigation is to develop a method for obtaining constant voltage from a generator driven by a hit-and-miss gasoline engine. Units of this type are frequently used in country home lighting plants and in other small power plants. When such a combination, having no voltage regulating device, is used to supply current to lamps, they do not give a steady light. An unpleasant fluctuation of light occurs, particularly at the instant the explosion takes place.

APPARATUS:

The apparatus used in the investigation was:

One 3 H.P. Hit-and-miss Gasoline Engine
One 3 H.P. 220 volt D. C. Motor
One Oscillograph containing three elements
One Lamp Bank
One Governor of special design
Rheostats and Electrical Measuring Instruments.

The engine and generator were mounted on a common base as shown in Fig. 1 and the generator was belted to the flywheel of the engine. A 10-inch pulley on the generator and a 26-inch flywheel on the engine gave a speed ratio of 2.6 to 1. The engine was a single cylinder Rock Island farm engine operating at

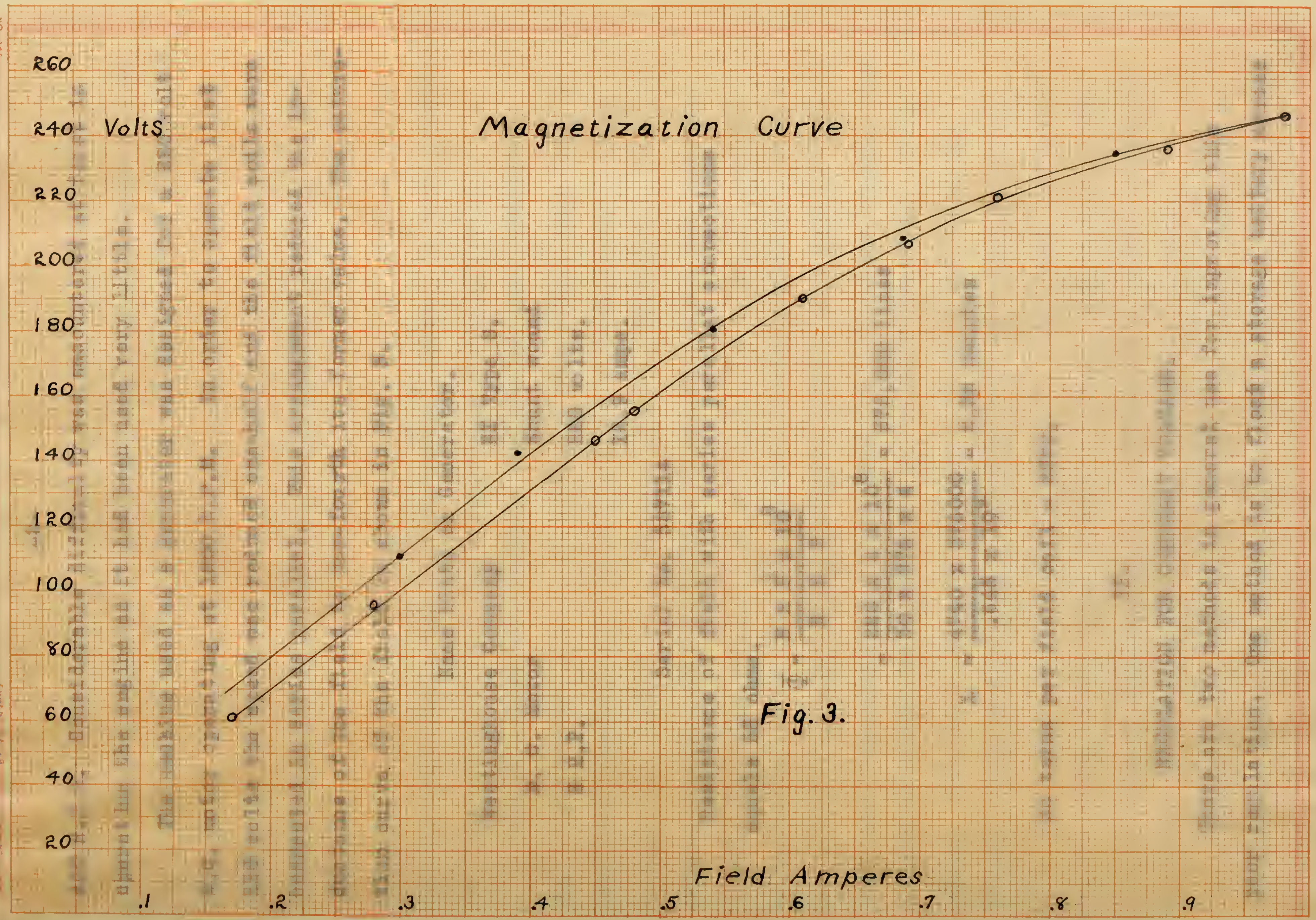
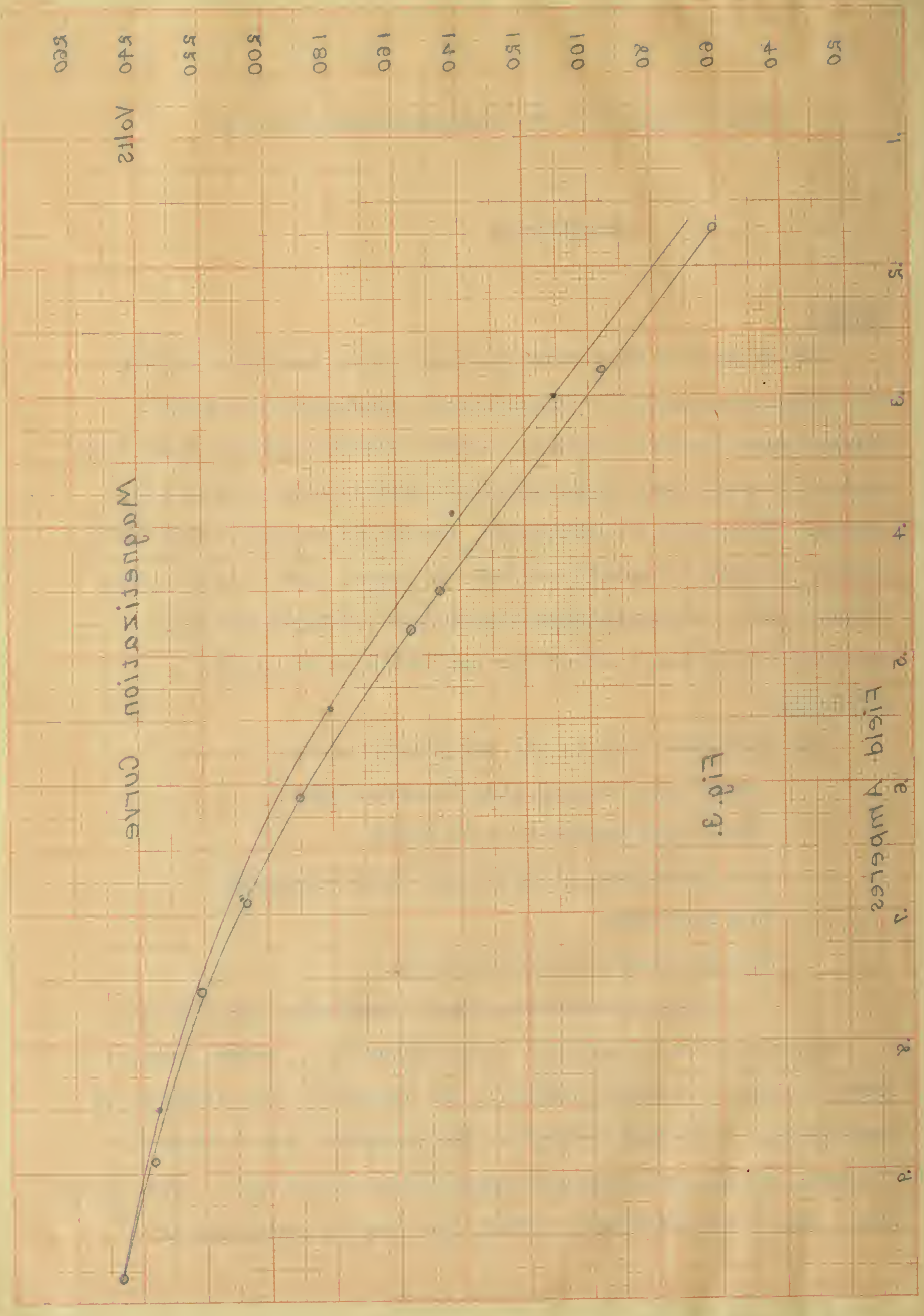

Magnetization Curve
Volts
260
240
220
200
180
160
140
120
100
80
60
40
20
Field Amperes
.1
.2
.3
.4
.5
.6
.7
.8
.9

Fig. 3.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.1
.2
.3
.4
.5
.6
.7
.8
.9

Fig. 3.

400 R.P.M. Considerable difficulty was encountered at first in operating the engine as it had been used very little.

The machine used as a generator was designed for a 220 volt D.C. motor operating at 1800 R.P.M. In order to operate it at 110 volts the speed was reduced one-half and the field coils were connected in series parallel. This arrangement reduced the inductance of the field to one-fourth its former value. The saturation curve of the field is shown in Fig. 3.

Name Plate on Generator.

Westinghouse Company	NI Type S.
D. C. Motor	Shunt wound
3 H.P.	220 volts.
	12.9 amps.

Serial No. 587114

Resistance of field with series parallet connections equals 55 ohms.

$$\Phi = \frac{E \times \overset{1}{P} \times 10^8}{N\ Z\ P}$$

$$= \frac{220 \times 2 \times 10^8}{30 \times 976 \times 4} = 376{,}000 \text{ lines}$$

$$L = \frac{4740 \times 376000}{.645 \times 10^9} = 2.38 \text{ Henries}$$

No turns per field coil = 2370,

II.

REGULATION FOR CONSTANT VOLTAGE.

There are two methods in general use for improving this poor regulation. One method is to float a storage battery across

the line. This, however, is expensive since the first cost is high and the battery deteriorates rapidly. The other method is to put a flywheel on the generator. Satisfactory results are obtained in this way if the flywheel is large enough and the engine has a sufficiently sensitive govenor, but the additional weight causes increased wear and strain on the machinery and the providing of a sensitive governor is not a simple matter. A fairly constant speed and satisfactory voltage regulation can be obtained by the use of a throttle governed engine which, however, is more expensive and less efficient than the hit-and-miss governed engine.

Several methods of attacking the problem were considered. The first involved the use of a Tirrill regulator. This type of regulator automatically varies the field current as the voltage changes, the control being effected electrically by the change in voltage itself. This method was abandoned because the necessary Tirrill regulator could not be obtained. This type of regulator is in common use in steam plants but its application to a generator driven by a hit-and-miss gasoline engine, the speed changes of whidh are more rapid, seems less feasible. The speed changes from maximum to minimum in approximately a quarter revolution of the engine. This is a comparatively short interval and since the voltage varies with the speed the regulator must operate during this time. Owing to the inductance of the field, time is required for the value of the field current to change, and it is doubtful if this type of regulator would operate quickly enough to prevent a flicker in the lights at the instant the engine fires.

Another purely electrical scheme is to insert inductance in the lines. This would be equivalent to putting a flywheel on the

generator. A variation in this method consists in placing a condenser between the generator and the inductance coils to serve as sort of a reservoir in which the electric charge can pile up after an explosion, this charge being given back to the line when the generator begins to slow down again. A diagram of connections is shown in Fig 2.

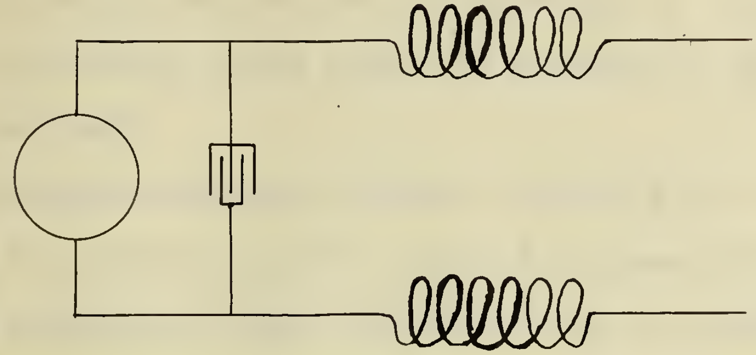


Fig. 2.

Assume the induced voltage to increase 5 volts in .15 second immediately after the explosion. This increase in voltage causes a current to flow into the condenser. This charging current flows through the armature causing an additional IR drop which reduces the voltage approximately to normal. Assume the armature resistance = .5 Ohms. Then, the charging current necessary to make 5 volts extra IR drop in the armature $= \frac{5}{.5} = 10$ amperes.

$$dq = idt = c\ de$$

$$10 \times .15 = c \times 5$$

$$c = .3 \text{ farads.}$$

This would be a condenser of enormous size and it is evident that this method would not be practical. A small storage battery might be put in place of the condenser; that is, floated on the line. The inductance would, in either case, tend to prevent sudden

surges of current in the line.

Another scheme, that of inserting a coil spring in the generator pulley, was also considered. This spring would coil up when the engine was accelerating and it would give back the energy, thus stored up, during the deceleration of the engine. This would have somewhat the same effect as a flywheel on the generator but it would possess the disadvantage of operating differently at different loads since the tension on the spring depends upon the load.

Next an electro-mechanical method of control was considered. In this method the field current is varied by means of a mechanical governor which actuates a field rheostat so as to keep the voltage constant. Three types of mechanical governors were possible; the centrifugal type, the inertia type and a combination of the two. The inductance of the field plays an important part in the selection of the type to be used. From the development of the theory it will be evident which type is applicable. The inertia type operates more quickly than any of the other types when there are rapid changes in the speed. It will not, however, be effective when the average speed is changed since it depends for its action upon acceleration and deceleration and not upon speed. In order to compensate for a change in the average speed a centrifugal governor would be necessary.

III.

AN ELECTRO-MECHANICAL GOVERNOR.

THEORETICAL CONSIDERATIONS:

The theory of the operation of the proposed method involves

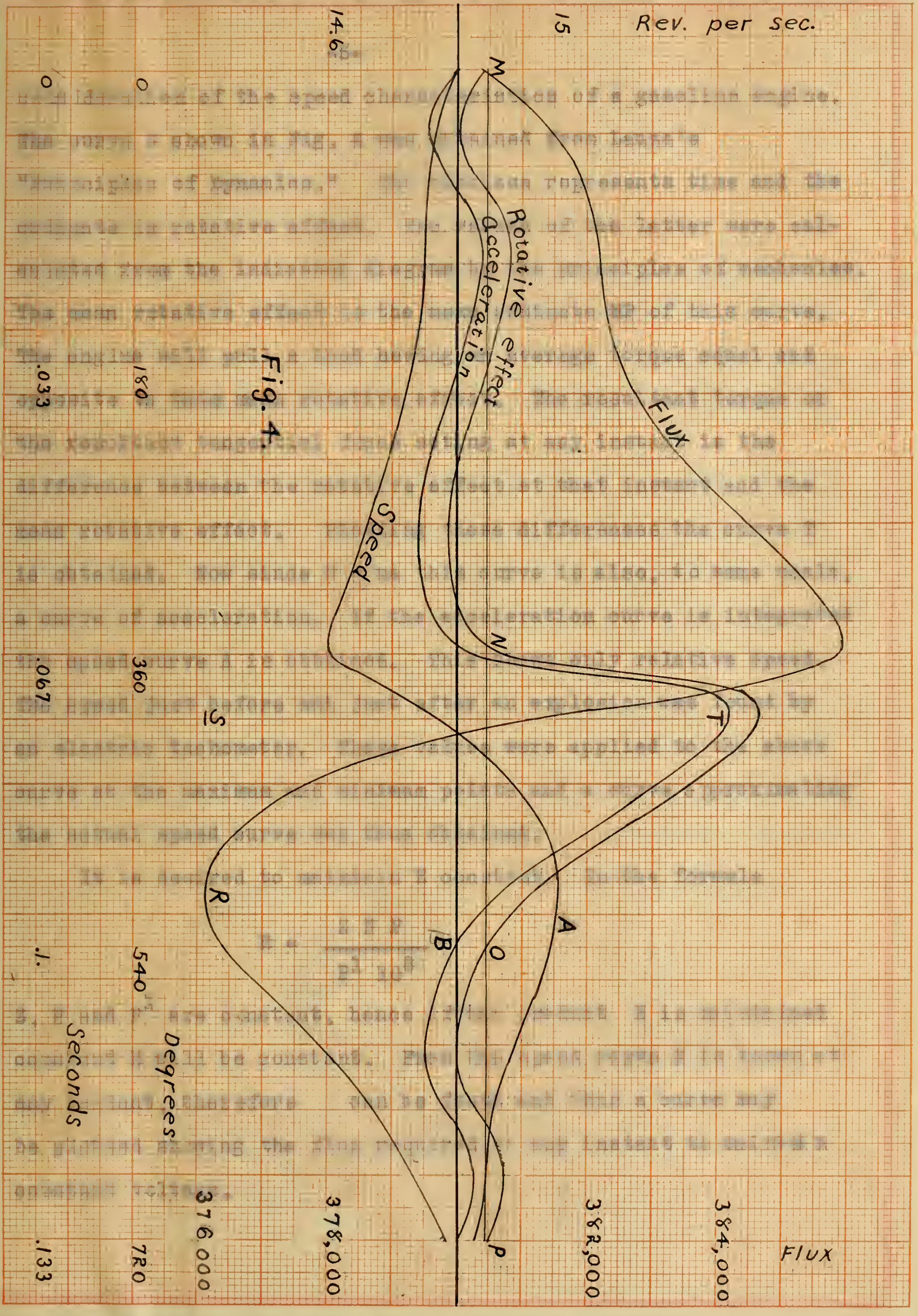
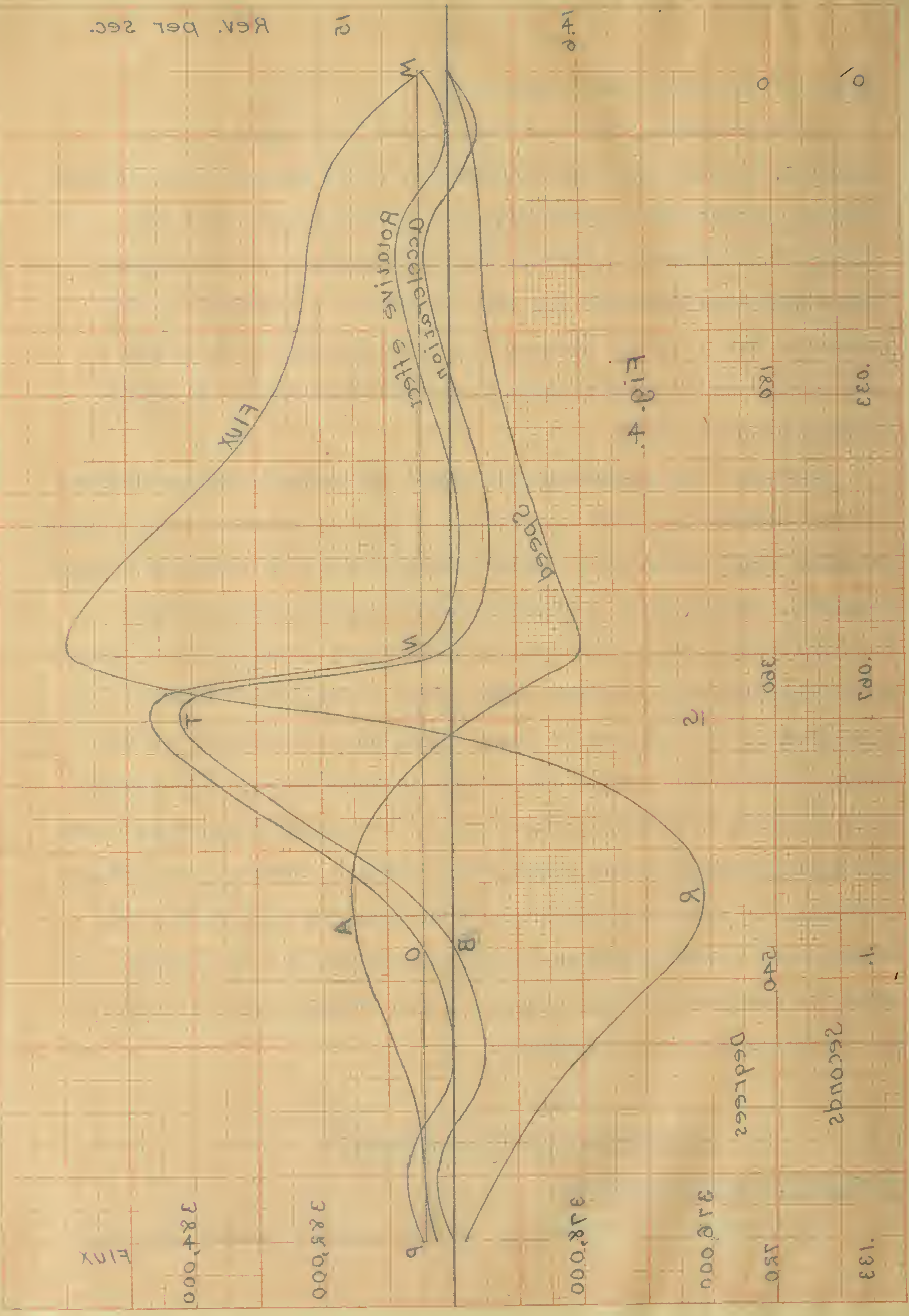

Rev. per sec.
15
14.6
0
0
.033
180
.067
360
S
.1
540
.133
720
Seconds
Degrees
376,000
378,000
382,000
384,000
Flux
M
N
T
A
O
B
R
P
Rotative effect
Acceleration
Speed
Flux

Fig. 4.


Flux
Rotative effect
Acceleration
Speed
M
N
T
A
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B
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Rev. per sec.
15
14.6
Flux
384,000
382,000
378,000
376,000
Degrees
0
180
360
540
720
Seconds
0
.033
.067
.1
.133

Fig. 4.

consideration of the speed characteristics of a gasoline engine. The curve N shown in Fig. 4 was obtained from Lanza's "Principles of Dynamics." The abscissa represents time and the ordinate is rotative effect. The values of the latter were calculated from the indicator diagram by the principles of mechanics. The mean rotative effect is the mean ordinate MP of this curve. The engine will pull a load having an average torque equal and opposite to this mean rotative effect. The resultant torque or the resultant tangential force acting at any instant is the difference between the rotative effect at that instant and the mean rotative effect. Plotting these differences the curve T is obtained. Now since F = ma this curve is also, to same scale, a curve of acceleration. If the acceleration curve is integrated the speed curve A is obtained. This shows only relative speed. The speed just before and just after an explosion was found by an electric tachometer. These values were applied to the above curve at the maximum and minimum points and a curve approximating the actual speed curve was thus obtained.

It is desired to maintain E constant. In the formula

$$E = \frac{Z\ N\ P}{P^1\ 10^8}$$

Z, P and P^1 are constant, hence if the product N is maintained constant E will be constant. From the speed curve N is known at any instant, therefore can be found and thus a curve may be plotted showing the flux required at any instant to maintain constant voltage.

[illegible]

[illegible]

$$[illegible]$$

[illegible]

From the formula

$$\Phi = \frac{.4\pi N I \mu A}{l}$$

it is possible to find the value of the field current I required at any instant. From the magnetization curve of the generator Fig. 3 it is seen that there is practically a straight line relation between Φ and I over the working range. Thus I is proportioned to Φ and the current curve is similar in shape to the flux curve.

The principle of operation of the proposed governor can best be shown in conjunction with these curves but the mechanism used will first be described. A disc of cast iron was machined to turn freely on the hub H (Fig. 6) of the generator pulley P. The motion is constrained, however, by the bumpers A and B so that as it moves back and forth the arm C will just sweep over the contacts P between which are the resistance steps N. It is held at about a middle position by the springs O and S. When the pulley revolvs at uniform speed these relative positions are maintained. When the

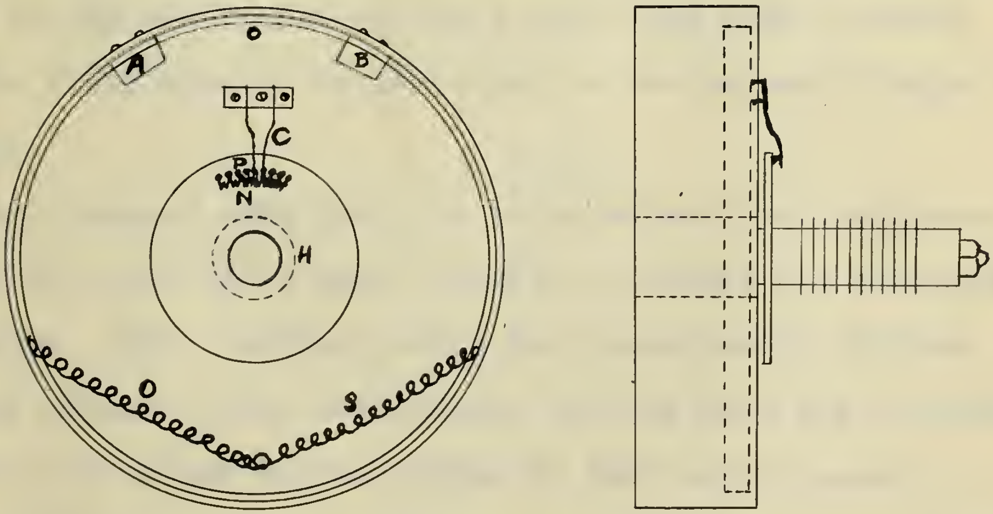

Fig. 6.

engine fires producing positive acceleration the disc lags behind and moves the arm C relative to the contacts so as to cut in resistance. When the acceleration is negative the disc moves ahead of the middle position and thus cuts out resistance.

From M to N on the curve T Fig. 4, the acceleration is negative and less than normal resistance is in series with the field. At N the acceleration becomes positive anc resistance is cut in. At B it becomes negative again and resistance is cut out. Thus it is seen that the rotative effect on the disc due to acceleration and deceleration of the pulley act in the right direction but a little before the required change in the field current. For example the maximum accelration occurs at the point T Fig. 4. If there were no inductance in the field the minimum current would occur at the same time, that is at the point S. The field current has its minimum required value at the point R a short time after the maximum resistance has been cut into the circuit. This condition is necessary to the successful operation of the governor owing to the inductance of the field which is large in comparison to the resistance of the field. The time constant (L/R) of the field circuit is large and so the current change is rather slow.

The next logical step would be to calculate the resistance which would be required at each instant to produce the required current curve. This, however, would be a complicated problem owing to the effect of the inductance. At any rate the resistance could not be cut in and out according to this curve because it must be applied in steps. For this reason it was decided to try

to determine the proper size of these resistance steps by experiment rather than by calculation. One case, however, was calculated in order to show whether the time of lag due to the inductance would be great enough to defeat our purpose.

Consider the extreme case which occurs just after the explosion. Here the rate of change of flux, or current since they are proportional, equals the slope of the curve. Consider a portion CD of the curve corresponding to an interval of time equal to .0275 seconds.

The resistance of the field is 55 ohms.

Assume that

Total initial resistance = r = 70 ohms
" final " = R = 80 ohms

It is desired to find the change in field current when the resistance changes from 70 to 80 ohms. For this purpose the following formula was developed.

$$i = \frac{E}{r} + E \left\{ \frac{r - R}{Rr} \right\} e^{-\frac{Rt}{L}}$$

$$i = \frac{110}{80} + 110 \left(\frac{80 - 70}{70 \times 80} \right) e^{-\frac{80 \times .0275}{2.38}}$$

$$i = 1.38 + .09 = 1.47 \text{ Amperes.}$$

Thus the current change will be

$$\frac{.09}{1.38} = .065 = 6.5\%$$

Under these conditions the field current will change 6.5% during the time corresponding to the length EF, Fig. 4. The voltage variation at the time of an explosion is not greater than 6.5% under normal operation, and since the worst condition has been

chosen it is reasonable to suppose that the inductance of the field will not be great enough to prevent the desired variation in the field current.

This conclusion is also sustained by curves of rise and decay of currents in an inductance coil. Rise of current in an inductive circuit follows a curve such as shown in Fig. 7.

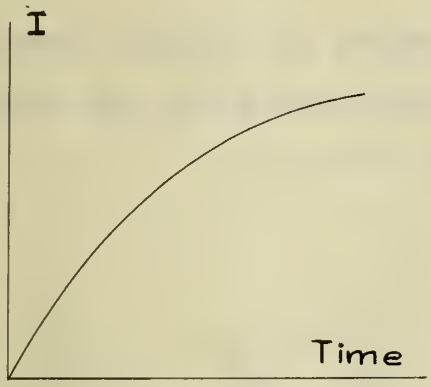

Fig 7.

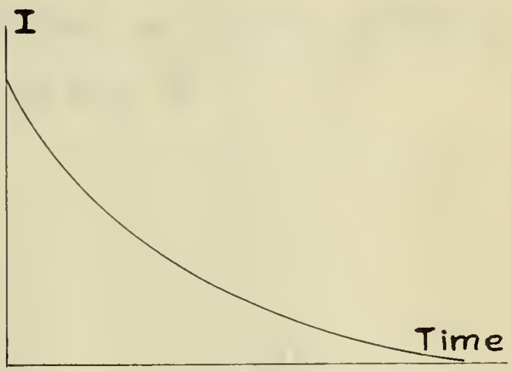

Fig 8.

while decay of current follows a curve such as shown in Fig. 8. The conditions of our problem require a rapid decrease in current at the time of explosion but at no time do they require an extremely rapid increase of current. This can be seen from the flux curve which is proportional to the current curve. The curves in Fig. 7 and Fig. 8 show that the laws of rise and decay of currents in inductive circuits suit the requirements of our problems.

PRELIMINARY DESIGN AND CONSTRUCTION:

In the design of a governor the following points were considered:

1. Size and weight of disc.
2. Type of contacts for the rheostat.
3. Number of contacts.
4. Proper size of resistance steps.

5. Type of spring.

6. Strength and characteristics of spring.

Reliable data could not be found upon which to base calculations for a careful design and hence some approximations were made. The size and dimensions of the disc were restricted by the size of the pulley. It was made of such size as to completely fill up the space inside the pulley. The disc as finally fitted in the pulley had the dimensions shown in Fig. 9.

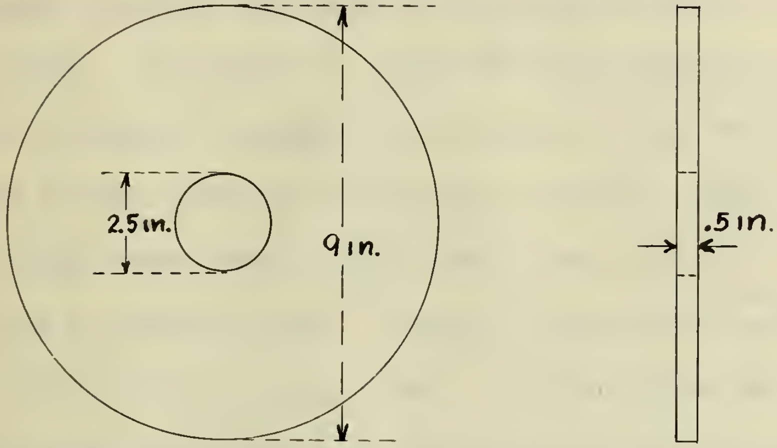

Fig 9.

Consider the force acting on the disc at the instant the engine fires.

Change in speed = .08 R.P. S.

Time = .0333 ÷ 9 = .0037 second.

$$\text{Acceleration} = \frac{.08}{.0037} = 21.6 \text{ Rev. per(sec.)}^2$$

$21.6 \quad = 68$ Radians per $(\text{sec.})^2$

Vol. of disc. = .5(9 - 2.5) = 10.5 cu. in.

$$\text{Wt. of disc} = \frac{1}{4}(10.5) = 2.62 \text{ lb.}$$

$$I = \frac{2.62}{2\text{x}32} \left(\frac{9}{24}\right)^2 - \left(\frac{2.5}{24}\right)^2 = .0053 \text{ lb (ft.)}^2$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Moment of force = M

$$= .0053 \times 68 = .36 \text{ lb. ft.}$$

Force acting 3 in. from center

$$= \frac{12 \times .36}{3} = 1.45 \text{ lb.}$$

The spring used for the first trial was a coil spring made from No. 20 piano wire. The rheostat arm C was made from a thin piece of spring brass. It was screwed to a fiber block and this in turn was screwed fast to the disc thus insulating the rheostat arm from the disc. In order to support the rheostat contacts a fiber disc was fastened rigidly to the end of the shaft. A row of small brass screws was set in an arc near the edge of this disc and the heads were were filed down level so as to make good contacts with the rheostat arm. Connections from these contacts were brought out to slip rings. This construction was used to facilitate changing the values of the resistance steps. This also obviates the construction of special resistance units which would be necessary if they were mounted inside the pulley. The slip rings were used for the experimental work only. If a commercial form of govenor were constructed the resistances would be mounted inside the pulley.

In order to mount the slip rings a hole was drilled and tapped into the end of the shaft to fit a one-half inch threaded steel rod. A block of hard wood was drilled to fit this rod, was slipped on the rod and fastened in place by a nut. This also served to clamp the fiber disc mentioned above. Using the generator as a motor this block of wood was turned down to fit snugly the small brass rings which constituted the slip rings. The

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

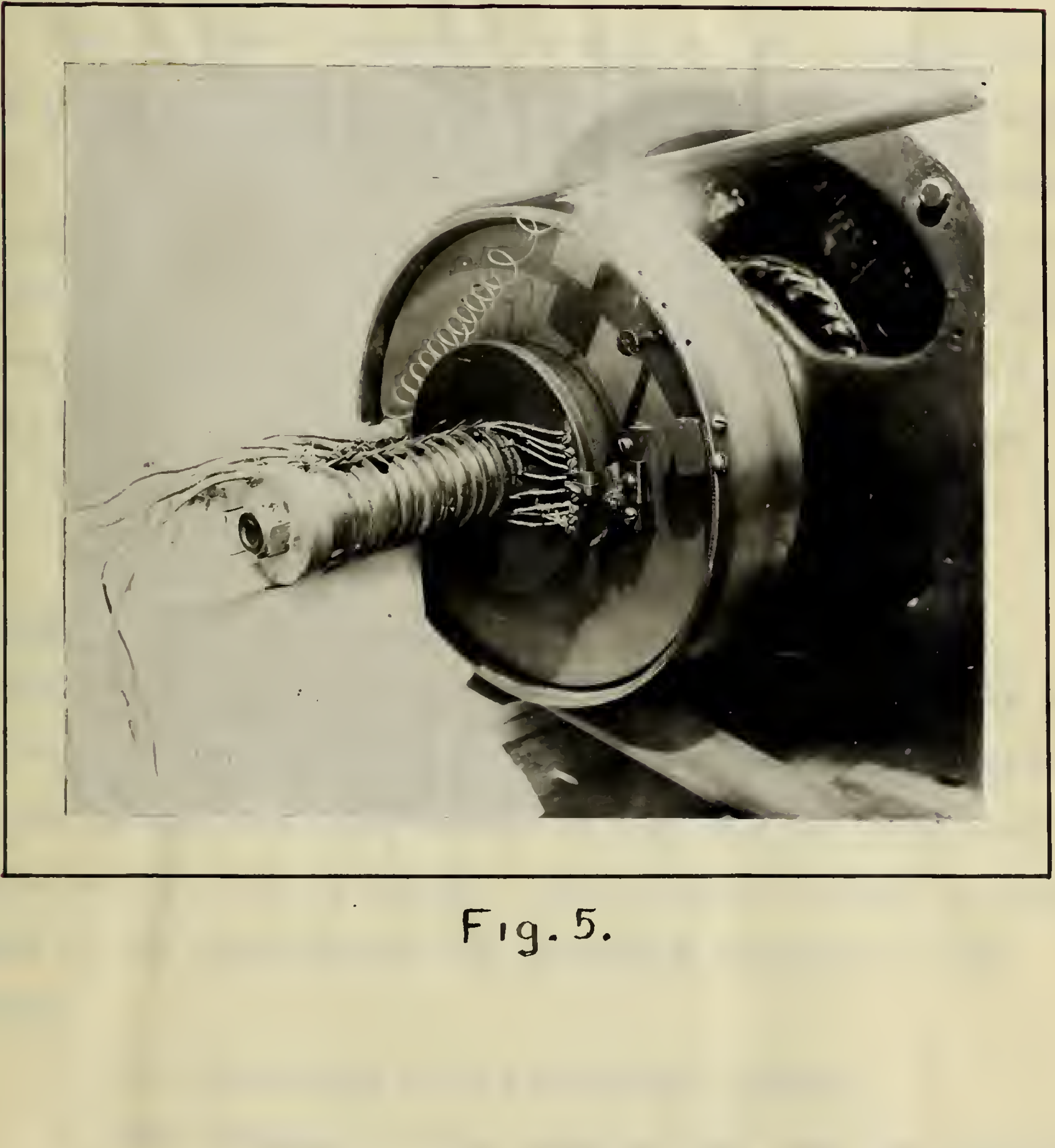

Fig. 5.

wires were then brought out through grooves cut in the wood and were soldered to the rings. The rings were insulated from each other by fiber washers. The brushes were made of strips of spring brass and were screwed fast to a block of fibre. There were nine slip rings corresponding to the nine contacts on the rheostat and one slip ring connecting with the rheostat arm. A sketch of this construction is shown in Figure 6.

This is also illustrated in Fig. 5. The wires shown at the left of the picture are connected through the slip rings to the contacts on the fiber disc and are led off to a number of rheostats. This makes it possible to vary the amount of resistance in each step while the pulley is in motion. It is also noticed that the spring brass contactor is split. This construction makes it more flexible so that it will follow up any irregularities in the contacts without causing an undue amount of friction.

INVESTIGATION OF THE BEHAVIOR OF THE GOVERNOR:

The governor having been constructed according to the above design the next step in the investigation was not to attempt to attain regulation but to determine if possible the operating characteristics of the governor. The attempt was made to determine by means of the oscillograph the following features of its operation:

1. The variation of the generator voltage.
2. The movement of the rheostat arm over the contacts.
3. The position of the crank of the engine relative to the above events.
4. The speed characteristics of the engine.

[illegible]

[illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]

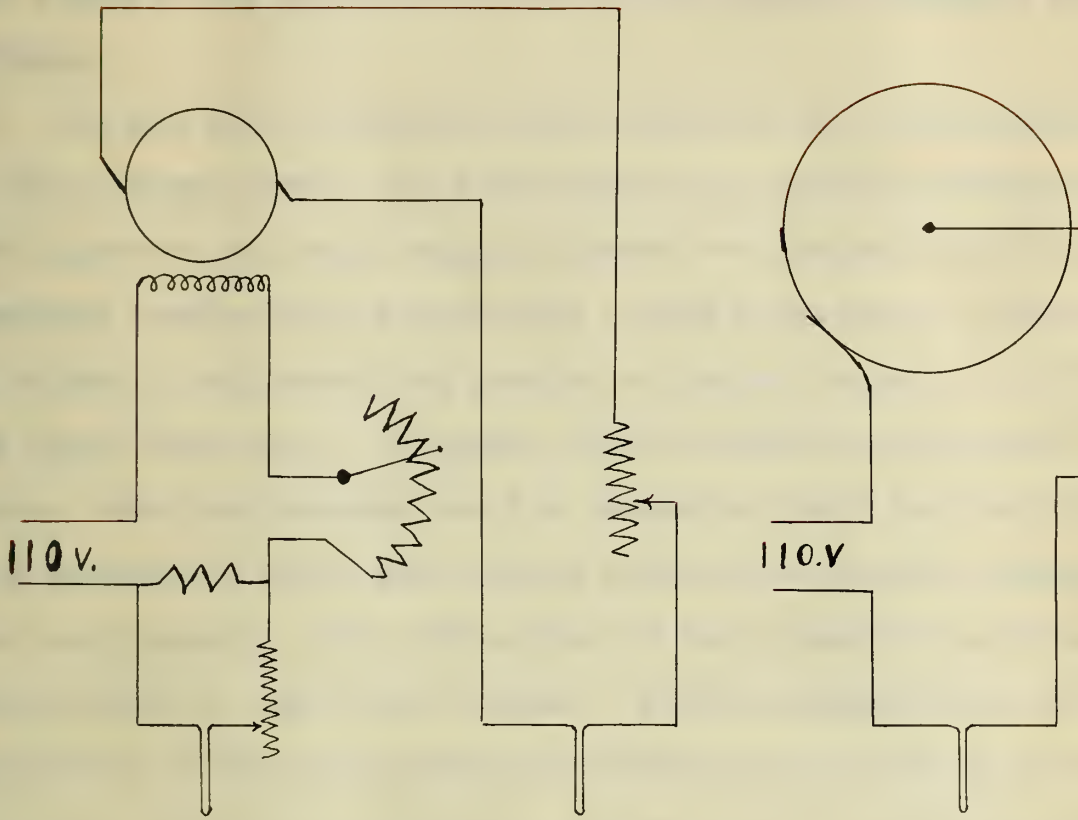

Fig 10.

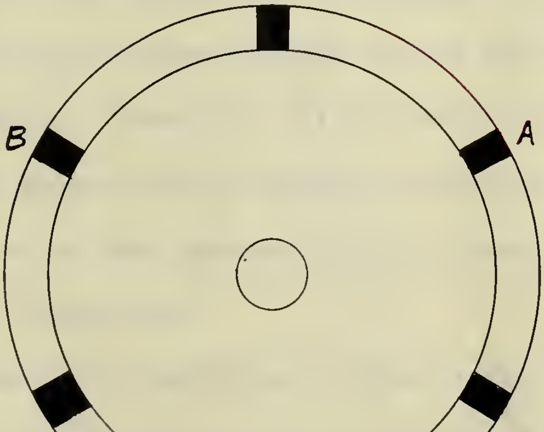

Fig 11.

With this information it was thought possible to adjust the values of the resistance steps in the rheostat and to determine the strength and characteristics of the springs required for our purpose.

To get this information the apparatus and connections shown in Fig. 10 were used. To investigate the voltage variation of the generator one oscillograph element was connected across the armature terminals in series with a high resistance, thus making in effect a very sensitive graphic voltmeter capable of following the rapid variations. A german silver shunt was connected in series with the governor and the generator field and the voltage drop across the shunt was used to actuate the second element of the oscillograph. The deflections of the element were thus proportional to the field current. As the acceleration and deceleration of the pulleycauses resistance to be cut in or out of the field circuit the resulting variation of the field current is recorded on the oscillogram which shows the movement of the governor. The field was separately excited so that the field current contained no variations except those due to changes in the governor resistance. Were the field self excited the variation of the field current would be due not only to the action of the governor but also to the change in the generator voltage caused by the speed variation.

In order to show the position of the crank of the engine at any instant a contact arrangement as shown in Fig. 11 was put on the flywheel. The points A and B were pieces of tape wrapped around the wheel to break the circuit at these points. One of these insulators was broader than the others to indicate the

position of the dead center. Incidentally it was also planned to obtain the speed variation of the engine by this scheme. Since the speed is different at different points of the engine stroke and since the film of the oscillograph travels at uniform speed the distance between the interruptions will vary. It was thought possible, by measurement of the distances between the points of interruption of the current, to obtain values which would give a curve of relative speed.

The oscillogram obtained from this arrangement is shown in Fig. 12. No one of the above plans was completely successful, for an examination of the curves shows that they give practically nothing of the desired information. The voltage variation as shown by MN Fig. 12 was so small as compared to the total voltage that it could scarcely be measured on the oscillogram. The movement of the rheostat arm could not be determined with any degree of accuracy, first because the inductance of the field made the changes of the field current slow so that it was uncertain at what point the rheostat arm changed from one contact to another. Second, because the variation of the field current was small as compared to the total field current. The oscillogram O.P. Fig 12 obtained from the flywheel contactor contained only meaningless deflections which were probably caused by the vibration of the engine.

The failure of these methods necessitated the use of other methods. As seen above the deflection on the oscillogram due to the variation in voltage could be only a small percentage of the width of the film and hence was difficult to measure. Considerable attention was given to the problem of magnifying this

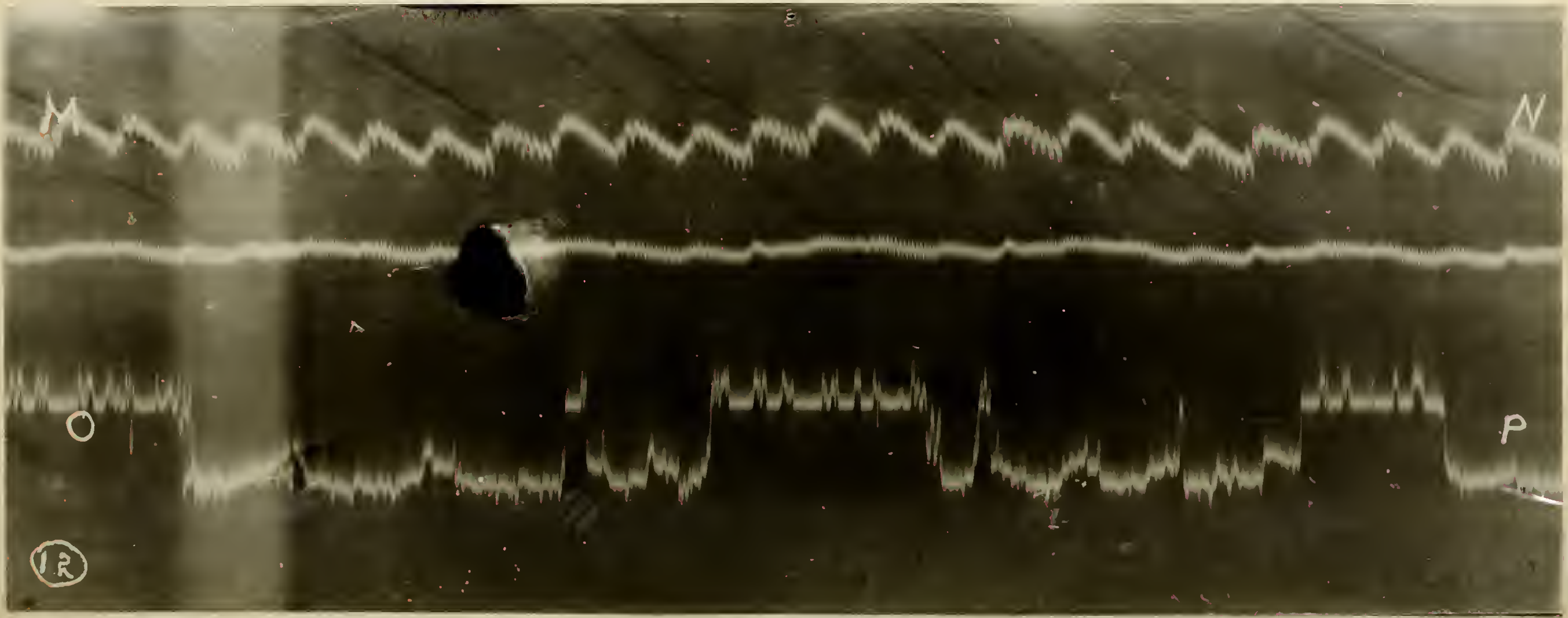

Fig. 12.

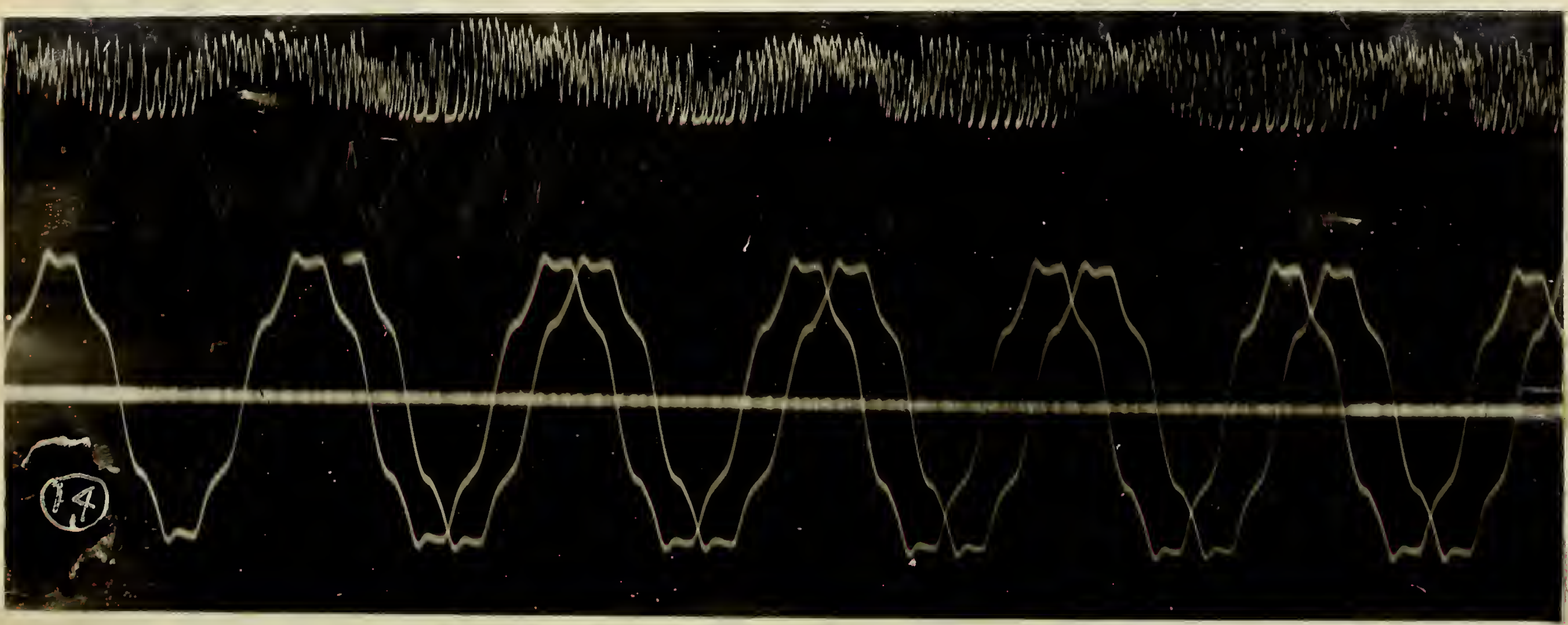

Fig. 14

deflection. Several methods for increasing the deflection were considered and some of them were tried out but proved unsuccessful. Finally a comparatively simple scheme, shown diagramatically in Fig. 13 was conceived. The working of this scheme depends on the fact that the generator e.m.f. and the constant e.m.f. of the battery act around the circuit of the oscillograph element in opposite directions and in consequence the voltage impressed on the element is always the difference between the generator e.m.f. and the battery e.m.f.

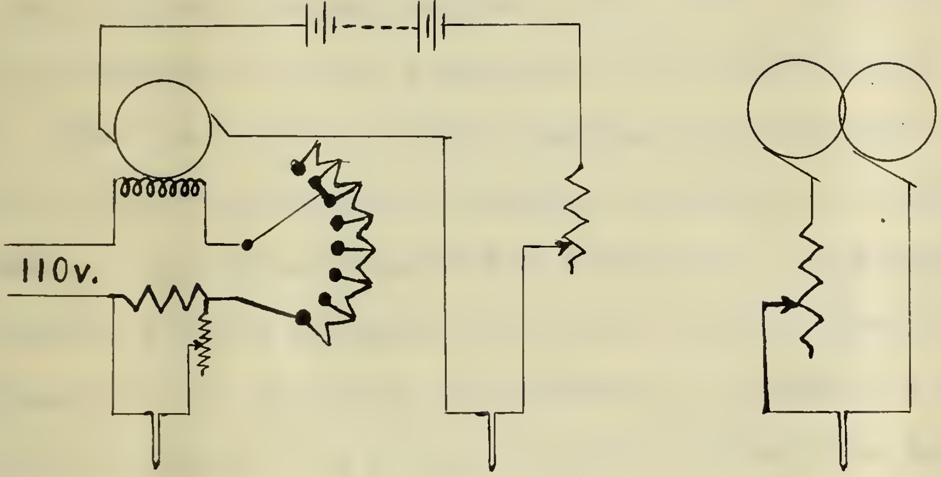

Fig. 13.

This opposition method proved to be a most successful way of making the voltage variations produce a large deflection capable of accurate measurement. Small variations which were almost invisible on oscillograms taken by the previous method became very large. In fact the deflection could be increased from about five per cent of the width of the film to a deflection covering the full width of the film. This means an increase of about twenty times the previous maximum deflection. This magnifying feature brings into prominence many irregularities in the so-called

continuous e.m.f. of the generator. Most of the irregularities which were brought out in such high relief were detrimental to the investigation. On the particular generator which was employed a distortion was found to exist in the e.m.f. wave which had a frequency corresponding to the number of poles and the speed of the generator. This distortion was found to be due to the presence of a dummy coil in the wave wound armature. In addition to this large distortion there were the smaller and more numerous commutator ripples.

The useless flywheel contact system was replaced by a small six pole alternator direct connected to the crank shaft of the engine. The e.m.f. wave of this machine was impressed upon one element of the oscillograph through a noninductive controlling resistance. The third element was connected, as in the previous case, across a shunt carrying the field current though this arrangement is not entirely satisfactory. To make the deflections proportional only to the change in field current the battery opposition method might have been used. The connections are essentially the same as in the e.m.f. circuit except that a shunt is employed as shown in Fig. 15.

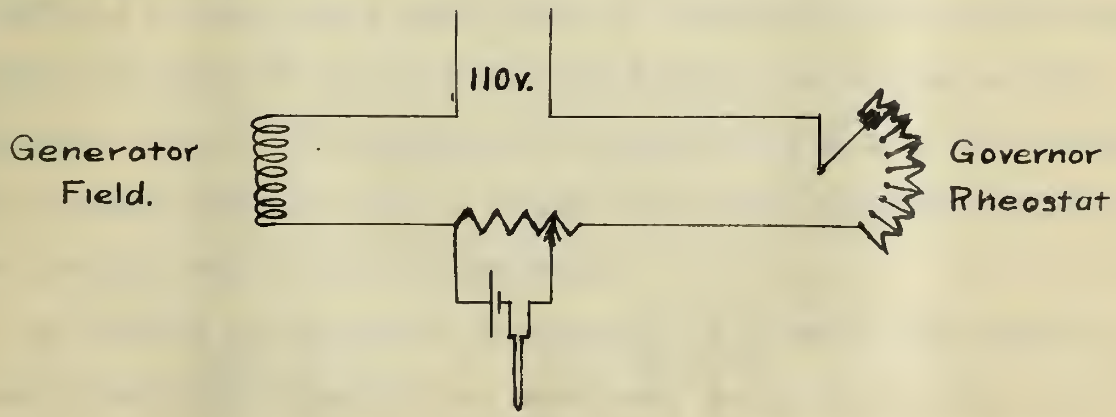

Fig. 15.

This method would make the field current variations presnet themselves in a much enlarged view with the same desirable result that obtained in the case of the voltage variations; that is, they would be large enough to be easily measured.

The film secured with this set up was much more satisfactory and instructive in many respects than the previous one. Owing, however, to the fact that the shutter of the oscillograph was not operating properly and was held open too long the greater part of the film moved twice past the slot through which the light beams played. As a result the multiplicity of waves on the film is rather confusing. The enlarged view of the voltage variations, however, is fairly clear. The small variations inherent in the e.m.f. of the generator have no noticeable effect on the lights though they show up in a very pronounced fashion on the oscillogram. This is due to the fact that they have a comparatively high frequency.

Those voltage variations due to the speed fluctuations which were the objects of primary interest might have been roughly separated from the other variations by drawing a curve through the high points of the deflections. This was not done, however, because more refined methods were used later to accomplish the same result. The field current was subject to considerable variation as the oscillogram shows. On account of the confusion due to the failure of the shutter the instants at which the events occurred relative to one another were rather uncertain.

The action of the small alternator in showing the position of the crank shaft at any instant was much more satisfactory than that of the contactor except that no provision was made to indicate when

the crank was at head end center. This indication might have been made by a mechanical arrangement to break the circuit for an instant at this point. While the apparatus was being adjusted to repeat this film one of the elements was burned out and could not be replaced. The investigation was henceforth limited to the use of the two elements.

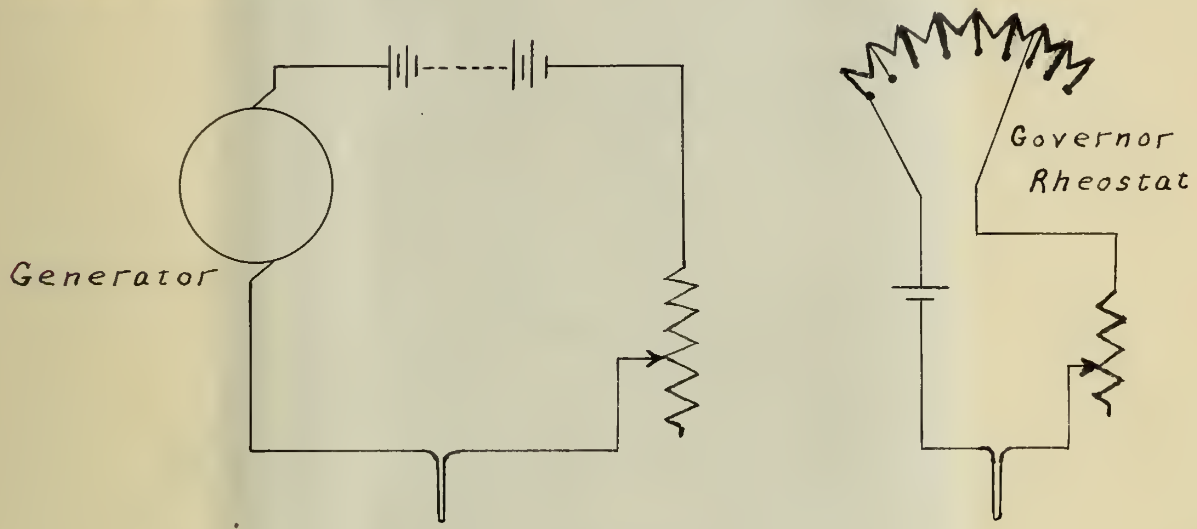

Fig. 16.

The element used to indicate the voltage variations was left connected as in Fig. 16. The other element was connected in series with the governor rheostat, a noninductive controlling resistance, and a dry cell as a source of e.m.f. The field coils were omitted from the circuit because the inductance of the field introduced a time lag into all the changes and because the resistance of the field was high as compared with that of the rheostat. With a dry cell and with a low resistance noninductive circuit the deflections were large and followed the other events without lagging. The oscillogram obtained by this method gave more exact information about the behavior of the governor than any of those previously taken.

The voltage variations were brought out in a striking manner

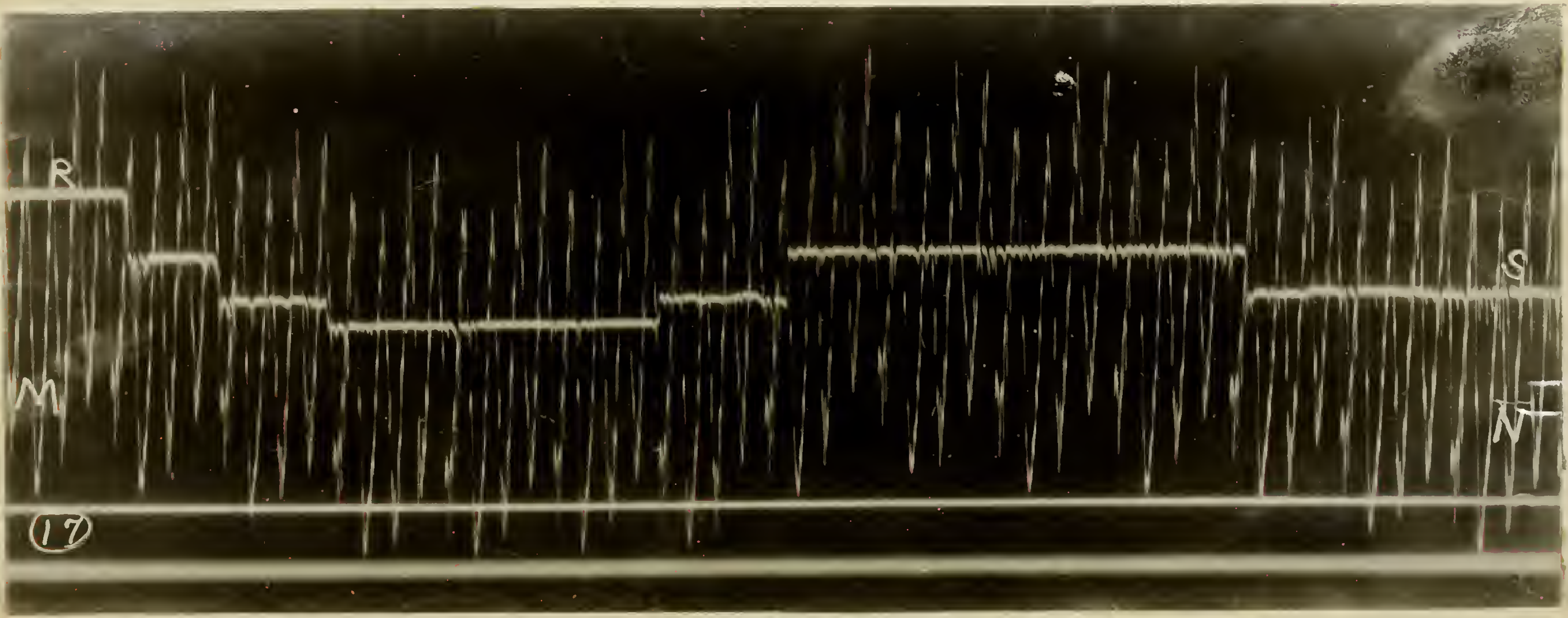

Fig. 17.

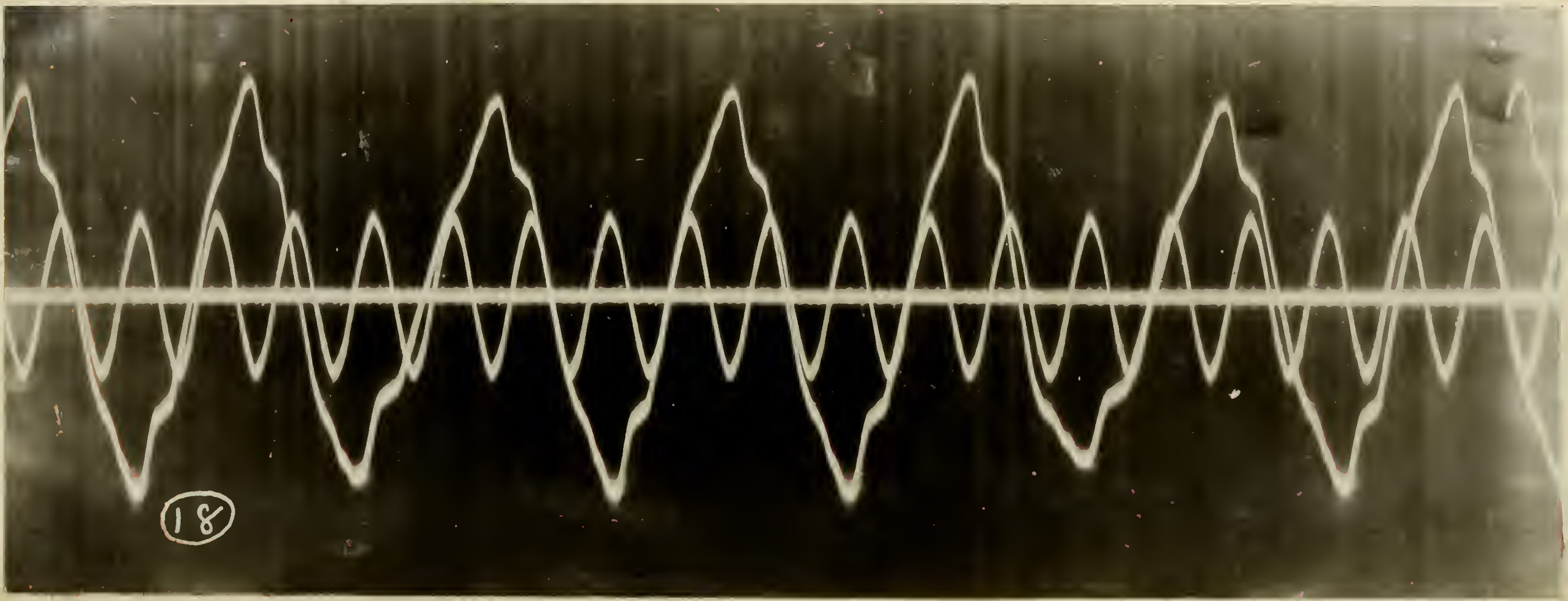

Fig. 18.

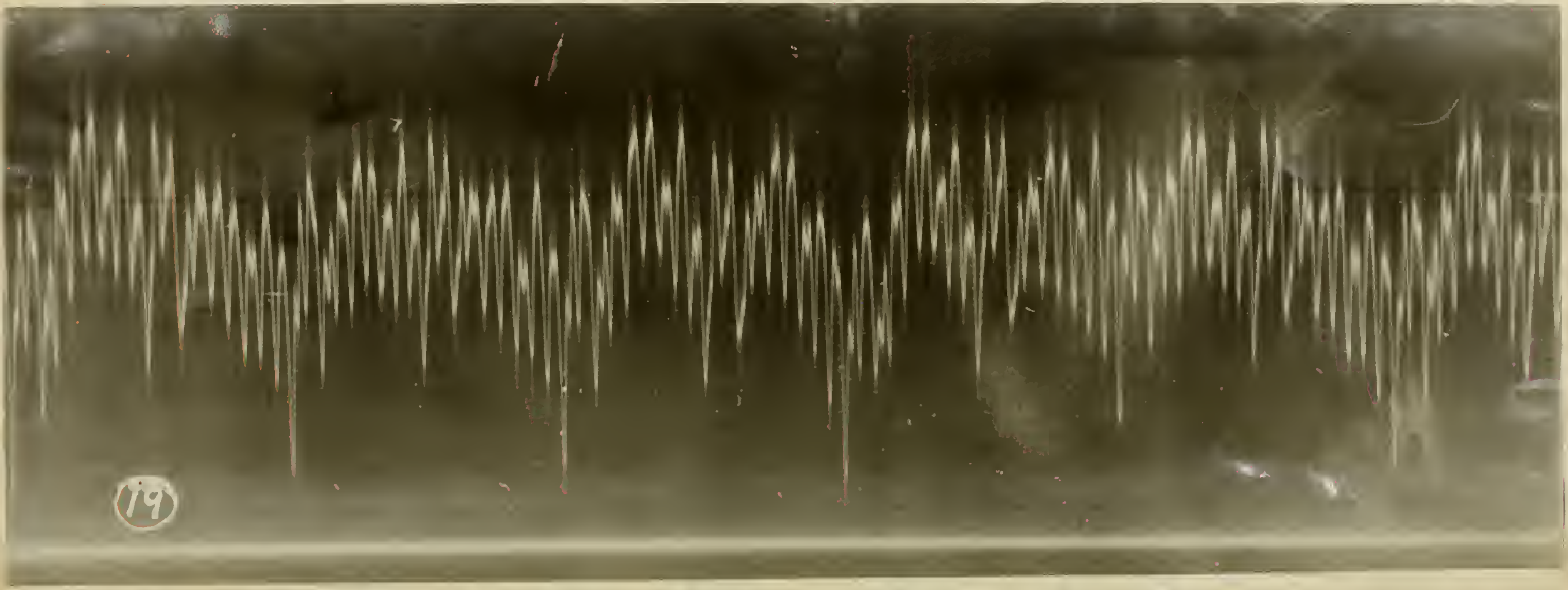

Fig. 19.

by the voltage curve MN Fig. 17. As the field excitation of the generator was constant the voltage variations are in a way a replica of the speed variations of the generator and, except for belt slip, of the speed variations of the engine. The broken line RS shows the relative position of the rheostat arm at different instants. Examination of the curve shows that when the e.m.f. is high the rheostat arm is in such a position as to cut in additional resistance and when the e.m.f. is low the governor cuts out resistance. This shows at least that the governor performs its function insofar as cutting in or out resistance is concerned.

The oscillogram shown in Fig. 18 is the result of one method for obtaining the speed characteristics of the engine. The large wave represents the e.m.f. of a small 6 pole alternator connected rigidly to the shaft of the engine. The smaller wave was taken at the same time and is merely a timing wave of 59 cycles. The time required for the film to traverse a distance of 1 inch was determined from the timing wave. The time required for a half cycle of the larger wave was then determined from its length. As the speed of the engine varied, the distance between the zero points of the wave varied also and so the average speed over a half cycle was directly proportional to the distance between two successive zero points.

The last attempt made to determine the speed characteristics of the engine involved the use of a small direct current generator which was thought to have an e.m.f. wave free from any very great irregularities. It was intended to attach this generator rigidly to the shaft of the engine and determine the speed changes by

the battery opposition method. First, however, an oscillogram was taken of the e.m.f. of the generator while it was driven at constant speed. The resulting wave Fig. 19, showed such irregularities in the e.m.f. that it was considered impracticable to use the generator for the purpose of determining speed variations. Time was not available to obtain a machine suitable for the purpose so the experimental work was discontinued.

CONCLUSIONS:

In the course of the experimental work very many obstacles were encountered which had to be overcome before the work which was actually planned could proceed. Troubles with the engine, the oscillograph and the governor were numerous and sometimes delayed the progress of the experiments for weeks at a time even after all the apparatus had been constructed. For this reason the time allotted for the experimental work had expired before enough information was obtained to either verify or disprove the practicability of the proposed governor.

A brief trial of the regulator was made using two ohms resistance in each step of the governor rheostat. It was hardly to be expected that the governor, designed from the rather meagre data available would improve the voltage regulation and indeed, it did not. In fact, the regulation was greater with the governor in the circuit than without it. This fact, however, does not necessarily mean that the idea of the governor need be abandoned for no attempt at adjustment, either of spring tension or of resistance steps, had been made.

From the beginning of the investigation considerable attention

was given to the problem of devising some method for obtaining the speed characteristics of the engine. The results obtained from using the small alternator direct connected to the engine shaft, though interesting, are not accurate for reasons previously given. The method of obtaining speed characteristics by opposing the e.m.f. of a storage battery to that of a direct current generator attached rigidly to the engine shows great possibilities. The curves obtained by this means show that the size of the deflections produced by the voltage variations is increased perhaps twenty times. If the generator has constant excitation it is evident that the variation in the speed is proportional to the variation in voltage. If use were made of a direct current machine which had no irregularities in its voltage other than the commutator ripples it is very probable that it would give excellent results. The application of this battery opposition method is probably the most unique method of attack in the entire investigation.

Some facts were observed which seem to indicate the possibilities of the governor. The curves in Fig. 16 show plainly the manner in which the contactor of the governor rheostat moves from point to point as the speed varies. This verifies the conclusions reached in the theoretical consideration of the problem. It shows that the inertia forces act at the right time and in the right direction to cut resistance in and out of the field circuit as required. It remains to be determined, however , if these resistance changes occur soon enough to counteract the retarding effect of the inductance of the field, so that the changes in

[illegible]

[illegible]

the field current may take place as required. Though the ultimate object of the investigation was not attained, those results which were obtained seem to indicate that, by proper adjustment of resistance steps, more refined mechanical construction, and the use of a leaf spring instead of a coil spring, a successful governor might be perfected.

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